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Originally published at:
Wieser, M; de Lange, V; Rodriguez del Rio, R; Vallery, H; Riener, R (2010). Control of Respiration via Posture and Movement: A Feasibility Study. In: Automed 2010, Zurich, 29 October 2010 - 30 October 2010.

Control of Respiration via Posture and Movement: A Feasibility Study

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Introduction

It is known that patients who need prolonged mechanical ventilation account for 5.8% of intensive care unit (ICU) admissions. Early rehabilitation is the key for this population, as longer stays in the ICU have been linked to higher mortality rates and reduced function [1]. An alternative or complementary treatment to mechanical ventilation and pharmaceutical intervention may be body tilting and passive mobilization. For the cardiovascular system, it has already been shown that verticalization and mobilization has a major positive influence [2, 3].

The Erigo tilt table allows passive verticalization of patients combined with passive leg stepping. With this system, we have recently demonstrated that heart rate and diastolic blood pressure of healthy subjects have a clear and repeatable response to body tilting and stepping [4].

This encourages the use of body tilting and passive mobilization to positively influence other physiological parameters, particularly breathing. Passive head-up tilt has been shown to increase tidal volume (VT) and minute ventilation in both healthy subjects and critically ill patients [1, 5]. However, in order to realize model-based control strategies, the specific relationship between mechanical stimuli and respiration parameters still needs to be found. In this feasibility study we look at this relationship for healthy subjects, specifically addressing whether respiration parameters can be controlled via body tilting and stepping.

Methods

Erigo and Measurement System

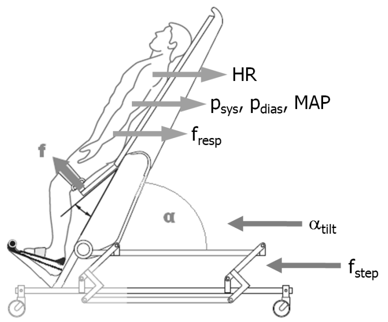

Fig. 1: Measurement setup showing the tilt table Erigo and the input variables tilt angle α_{tilt} and stepping frequency f_{step}. The physiological output signals are: heart rate *HR*, systolic, diastolic and mean arterial blood pressure p_{sys}, p_{dias} and *MAP*, as well as respiration frequency f_{resp}.

The tilt table Erigo (Hocoma AG, Switzerland) combines a continuously adjustable tilt table with an integrated motor-driven stepping device. The tilt angle α_{tilt} can be adjusted between 0° and 76° (velocity: 3.4°/s) and the stepping frequency f_{step} can be regulated between 0 and 80 steps per minute (Fig.1).

Respiration was recorded with a SleepSense thermistor-based airflow sensor (St. Charles, USA), placed just below the subjects' nostrils. We also recorded heart rate (*HR)* using a biosignal amplifier from Guger Technologies (Austria) and blood pressure (p_{sys}, p_{dias}, *MAP*) with a CNAP Monitor 500 from CNSystems (Austria).

Subjects

Eleven healthy subjects (4♂, 7♀) with no cardiovascular history participated in this study. The subjects were all non-smokers with an average age of 24.7 (SD: ± 2.2), height of 1.74 m (SD: ± 0.07), and weight of 62.2 kg (SD: ± 7.2). Subjects were not informed about specific aims regarding respiration parameters.

Protocol

A baseline measurement was recorded for 10 minutes in a supine position prior to the initial tilt. The normalized height h_{norm} in all subjects is determined by $h_{norm}=\sin(\alpha_{tilt})$. Subjects were tilted to 20°, 40°, 60° and 76°, for 3 minutes in a random order, always returning to the supine position between tilts (also for 3 minutes each). A second baseline was recorded for 10 minutes after the final tilt. The procedure was performed at 3 different stepping frequencies: 0, 24, and 48 steps/minute.

Data Analysis

Respiration rate f_{resp} was calculated by extracting the peaks (end of inhale) and the troughs (end of exhale) from the flow signal. The relative value of the VT was estimated by numerically integrating the flow signal.

Results

After analyzing the respiration data, two groups with distinct responses could be identified. The first group (n= 4) will be called the increasing-volume group (IVG); as the height of the heart increases from $\sin(20^o)$ to $\sin(76^o)$ the VT clearly increases and the respiration rate linearly decreases (Fig.2).

The second group (n=5; called the increasing-frequency group – IFG) exhibits the opposite response. The respiration rate is clearly elevated at a normalized height of sin(76°). In contrast to the IVG, the response from this group is highly variable, and for normalized heights of sin(40°) and sin(60°), no clear change in respiration rate is observed. In general, the VT decreases as normalized height increases.

Two subjects were excluded from the data analysis because it was not possible to identify cycles of tidal breathing in a clear and robust way.

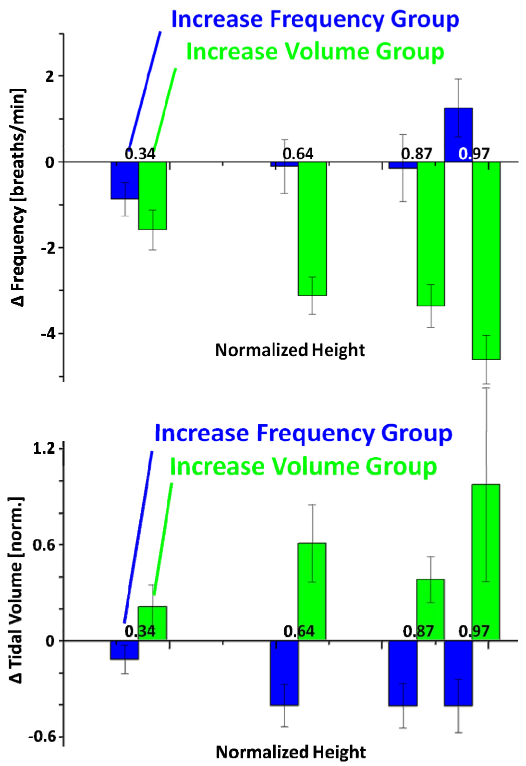

Fig. 2: The average change (with SD) in breathing frequency and tidal volume (VT) versus normalized height.

For both groups, the respiration rate was higher with stepping (data not shown). The results did not indicate that this increase was caused by synchronizing breathing rate with the stepping frequency. The VT data is even more variable when stepping is introduced and no conclusions could be drawn concerning the effects of stepping on VT.

Discussion

The subjects in the IVG take slower and deeper breaths as the change in the height of the heart increases. They are calm during tilting, and any parameter changes are likely caused by physical changes to the respiratory system.

It is widely accepted that tilting increases a person's functional residual capacity (FRC), as a result of the abdominal contents shifting and the diaphragm descending. This increase in FRC causes the VT to increase. The decrease in respiration rate can be explained by the increase in VT. More oxygen is taken in with each breath, reducing the number of breaths needed.

In contrast, subjects in the IFG begin to take more rapid and shallow breaths. Tilting may have increased the subjects' anxiety and elevated the activity of the sympathetic nervous system (SNS). Stimulating the SNS causes the airways to dilate, resulting in rapid, shallow breathing. This physiological change causes the subjects to increase their respiration rate and decrease their VT.

Concerning tilting and stepping, literature does not yet report two distinct groups. However, it could be observed that most of the studies had a majority of male subjects. In our study, the IFG is mostly female (1♂, 4♀), implying that gender differences could be a reason for the two groups.

Based on these preliminary results, the respiration control strategy might have to be individualized; the respiration frequency would be appropriate for the IVG, and the VT for the IFG. However, it is also possible that the two groups are using different strategies to make the same adjustments to the respiratory system. This means that an invariant control variable could potentially be identified, such as the product of the two variables (corresponding to the respiratory minute volume).

Conclusion & Outlook

We can identify two different responses to body tilting within 9 healthy subjects. The first group takes slower and deeper breaths as the change in the height of the heart increases, whereas the second group begins to take more rapid and shallow breaths.

In order to get appropriate variables for a robust respiration control strategy, more subjects will be measured with an Oxycon-System, which provides detailed information about volume and gas concentrations during body tilting and stepping.

Literature

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Acknowledgments

This project was funded by the NCCR (National Center of Competence in Research) Switzerland. Special thanks to G. Colombo and A. Dodge for their technical support.